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TRACE FOSSILS FROM TWO UPPER PENNSYLVANIAN SANDSTONES IN KANSAS

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ABSTRACT

Trails and burrows from two sandstones of the Upper Pennsylvanian of Douglas County, Kansas, are described and interpreted. Some of these are known from the literature, others are new. The trace fossil fauna suggests deposition of the sandstones in littoral shallow water. Although shelly fossils in both units are similar, the differences in the two trace-fossil faunas which have only two species in common indicate presence of two different environments.

INTRODUCTION

During the spring of 1966, while attending the University of Kansas, I had opportunity to study the Pennsylvanian rocks in Kansas. This paper is concerned with two rock units in the neighborhood of Lawrence, Douglas County, Kansas, which include sandstone beds containing abundant, well-preserved trace fossils. Two outcrops, one close to Eudora (Killough quarry, NW ¼ sec. 20, T. 13 S., R. 21 E.) and the other at Blue Mound (NE ¼, SW ¼ sec. 22, T. 13 S., R. 20 E.), were studied in detail and trace fossils from the sandstones were collected.

The sandstones studied at the Killough quarry near Eudora are part of the Rock Lake Shale Member of the Stanton Limestone of the Lansing Group, Missourian Stage, Upper Pennsylvanian, and those studied at Blue Mound belong to the Vinland Shale Member of the Stranger Formation of the Douglas Group, Virgilian Stage, Upper Pennsylvanian (Fig. 1). Both sandstones are of marine origin.

The sandstones of the Rock Lake Shale contain *Myalina* and *Aviculopecten*, in addition to other less common marine fossils. The Rock Lake Shale Member is overlain by the South Bend Limestone Member, a fossiliferous limestone with abundant fusulinids and several species of brachiopods. The base of the Rock Lake Shale is formed by the Stoner Limestone containing fusulinids, bryozoans, brachiopods, crinoids, and echinoids.

Sandstones of the Vinland Shale at Blue Mound contain *Myalina*, and shales interbedded with them contain septarian concretions with a brachiopod and molluscan fauna. The Vinland Shale is overlain by the Haskell Limestone containing a rich marine fauna, and underlain by the Westphalia Limestone which contains ostracodes and tiny gastropods.

The fossil assemblages in the sandstones and in the underlying and overlying limestones of both units indicate a marine environment of deposition of the two members. Stratigraphically the two units are not far apart and the fossil content is similar.

Fossil tracks, trails, and burrows resulting from biological activity furnish information about the sediment in which they are found. The origin of many tracks, trails, and burrows is difficult to interpret and resulting conclusions are uncertain. However, trace fossils have the advantage of being definitively autochthonous; they are, therefore, important for interpretation of paleoenvironments.

SEILACHER (1964) divided trace fossils into the following five ethological groups: 1) Repichnia—trails or burrows made by animals of the vagile benthos during locomotion; 2) Pascichnia—winding trails or burrows made by vagile mud-eaters, reflecting a "grazing" activity in search for food, covering a surface more or less efficiently and avoiding double coverage; 3) Fodinichnia—burrows made by semisessile deposit-feeders in search of food, at the same time providing permanent shelter; 4) Domichnia—permanent shelters dug by vagile or semisessile animals that procure food from outside the sediment as predators, scavengers, or suspension-feeders; and 5) Cubichnia—shallow resting tracks left by vagile animals hiding temporarily in the sediment, usually sand, and obtaining their food as scavengers or suspension-feeders.

All groups, except the last, could be recognized in the two sandstones studied.

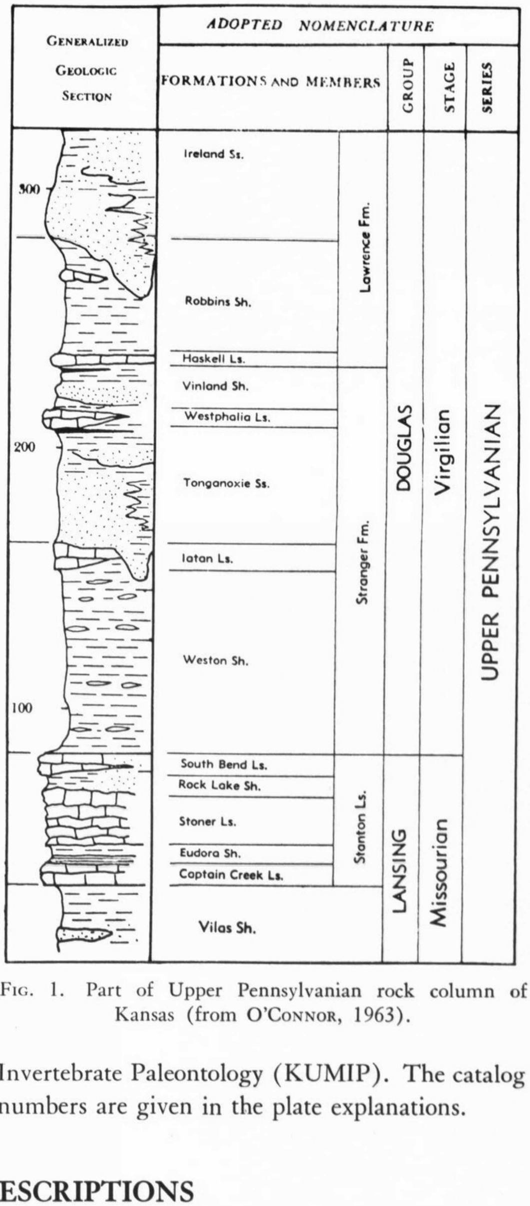


FIG. 1. Part of Upper Pennsylvanian rock column of Kansas (from O'CONNOR, 1963).

Type specimens and others illustrated are deposited in the University of Kansas Museum of Invertebrate Paleontology (KUMIP). The catalog numbers are given in the plate explanations.

SYSTEMATIC DESCRIPTIONS

Following practice adopted by HÄNTZSCHEL (1962), the trace-fossil genera are described in alphabetical order.

Genus ASTERICHNUS Bandel, n. gen.

Type species.—Asterichnus lawrencensis BANDEL, n. sp.

Diagnosis.—Starlike tracks in sediment just above sediment-covered bedding plane; non-branching star rays.

ASTERICHNUS LAWRENCENSIS Bandel, n. sp.

Plate 1; Plate 2, figure 4,6 Figure 2,*3*.

Diagnosis.—Starlike tracks with diameter of 4 to 12 cm., consisting of rays 5 to 8 mm. wide, in form of grooves or tubelike ridges; center of each track consisting of oval to round ridge; number of unbranched rays 10 to 30.

Description and discussion.—Single star tracks, preserved as epireliefs, have a diameter of 4 to 12 cm. and are approximately circular in cross section.

Each track consists of 10 to 30 rays which are grooves, 5 to 8 mm. wide, that may be partly filled by cylindrical structures (Pl. 1; Pl. 2, fig. 4). The centers of the star tracks are irregularly oval knobs, some of which appear to consist of overlapping circles. The star tracks seem to show preference for ripple crests on bedding plane surfaces buried by sediment penetrated by the track-making organism (Pl. 1; Pl. 2, fig. 4,6). Rarely two structures may overlap somewhat, but usually they are set far enough apart not to overlap.

The central knob of most starlike tracks appears to be a broken-off tube that leads upward into the burrow of the animal that made these tracks. The overlying sediment into which the burrow projected, is a silty clay, rich in iron sulfide and containing many fragments of wood. Wood fragments are also common on the upper surface of the sandstone beds, but are not present in them.

A section through the middle of one star structure showed that the tube does not continue downward into the sandstone. Close to the central part of the star tracks some tubelike sand-filled ridges coated by silt on the outside are preserved. These ridges continue into grooves at their end where some of them are broken off.

Origin.—The animal that produced these structures must have had its dwelling burrow in the silty sediment above the sandstone bed on whose rippled surface the star tracks are superimposed. The tracks can be interpreted as feeding tracks made in very much the same way as starlike structures are made by sediment-dwelling organisms on the surface of the sediment. The animal doubtless extended part of itself from the burrow along the bedding plane, taking in sediment of this area, extracting food particles from it, and refilling part of the feeding burrow with waste sediment. The cylindrical ridges are interpreted to be refilled parts of the feeding burrows and the grooves are inferred to mark the primary burrows made by the feeding animal. The animals closely followed the irregular bedding plane. They preferred the ripple crests as the center of their feeding tracks and fed in a circle all around the crests, covering almost entirely areas 8 to 14 cm. in diameter. The animals did not burrow into the sandstone. It is likely that after extracting all food in one circular area, they moved away to find another spot, as yet untouched. It can be noted that the starlike tracks are found in a kind of linear pattern on the sandstone surface, suggesting movement of one or several animals in search of new feeding grounds. A few of the starlike tracks are connected by grooves, suggesting a trail made by movement of the animal on the sandstone surface. Again, the close similarity of these subsurface tracks to surface tracks of *Scrobicularia plana* of the North Sea tidal flats (Schäfer, 1962) can be noted. This bivalve moves from one feeding area to the next close to the sediment surface, making a groove between the star tracks.

It cannot be decided what kind of animal made the tracks named *Asterichnus*. The large variety of animals that can produce star tracks on the surface of sediment calls for caution. However, it seems certain that it must have been a relatively large organism, in which the organs used for feeding had a diameter of about 5 to 8 mm.

The manner in which *Asterichnus* tracks were made, that is along bedding planes in the sediment, not on the sediment surface, distinguishes them from all other known Recent and fossil star tracks. Schäfer (1962) described and illustrated grazing tracks of the bivalves *Macoma baltica* and *Scrobicularia plana* from North Sea intertidal flats. These grazing tracks are strikingly similar to *Asterichnus*, but are formed on the sediment surface. Häntzschel (1939) described starlike tracks of the small intertidal-flat-dwelling amphipod, *Corophium*. A very peculiar producer of star tracks is a fish, *Gobius microps*, of the intertidal flats of the Baltic Sea (Häntzschel, 1935). Nathorst (1900) described star tracks made by the annelids *Glycera alba* and *Gonidia maculata*, which live on muddy bottom in the North Sea at a depth of 15 feet. *Nereis*, a polychaete worm, also produces starlike feeding tracks (Häntzschel, 1940). The star track *Paleocrista ostthuringiacus* Hundt (1941), from the Ordovician Phycodesschichten of eastern Thuringia, has been interpreted as being of worm origin, and *Spongia ottoi* Geinitz, from Cenomanian sandstone of Saxony, as of brachyuran origin. Other star tracks are known, but all differ in origin from *Asterichnus*, because they were formed on the surface of the sediment.

Occurrence.—Rock Lake Shale Member at Eudora, Douglas County, Kansas. Some 50 tracks are preserved on two large sandstone slabs.

Holotype.—Museum of Invertebrate Paleontology, University of Kansas, no. 25146.

Genus ASTEROPHYCUS Lesqueraux, 1876

ASTEROPHYCUS sp.

Plate 2, figure 1,2; Figure 2,*7*.

Large burrows preserved in epirelief approximately parallel to bedding planes radiate from a central tube that reaches to the surface of the sediment (Pl. 2, fig. 1, 2; Fig. 2,7). The radial burrows have irregularly oval cross sections that are 10 to 25 mm. in diameter. The burrows have a longitudinally wrinkled surface (Pl. 2, fig. 2).

Preservation of these structures on the surface of a bedding plane indicates that the hidden burrow was washed out by current action and subsequently buried again. SEILACHER (1962) has reported burrow structures uncovered by turbidity currents in flysch psammites.

Asterophycus structures could have been made by wormlike animals or by crustaceans.

Genus AULICHNITES Fenton & Fenton, 1937

AULICHNITES sp.

Plate 2, figure 3,5; Figure, 3,*1*.

Crawling trails, probably of gastropod origin, are found in great number on the surface of sandstones at Blue Mound and at Euroda (Pl. 2, fig. 3, 5; Fig. 3,*1*). The trails at Eudora are hyporeliefs on the under surfaces, the trails from Blue Mound epireliefs on the upper surfaces of beds. One trail is only 2 mm. wide, but most are about 6 mm. The preservation of specimens in the Vinland Shale is poor, but the Rock Lake Shale trails are excellently preserved.

Two convex ridges are separated by a median groove. The surface of the ridges is usually smooth; only in a few specimens are the outer edges undulating (Pl. 2, fig. 3), or transverse ribs are formed on the convex ridges. The trails show no preferred direction; many cross each other or they run parallel for a short distance. They seem never to have been used twice. Some of the trails are only imprinted on top of ripples and do not continue in the ripple valleys.

ABEL (1935, fig. 179-195) showed that a single species of gastropod can produce many different trails. SCHÄFER (1962, p. 302) described trails of *Littorina littorea* and found that locomotion of this snail on a soft substrate caused a transversely segmented trail, while locomotion on a hard substrate formed a smooth trail. The Rock Lake Shale gastropod trails show the same differences.

SEILACHER (1953) differentiated between grazing trails of gastropods and trails caused by locomotion of gastropods without grazing. Grazing animals stay close to older trails because they mark the best feeding grounds. If possible, the animals avoid previously grazed areas and, if necessary, cross over them in the shortest possible way. The result of this grazing behavior is a number of crossing, curving trails (Pl. 2, fig. 5). The animal which is moving from one place to another without grazing leaves a more or less straight trail. SCHÄFER (1962, p. 303) does not object to the idea of distinction between grazing and locomotion trails, but finds that Recent trails of gastropods cannot always be classed as one or the other.

Genus CHONDRITES Sternberg, 1883

CHONDRITES GONIDIOIDES Wanner, 1949

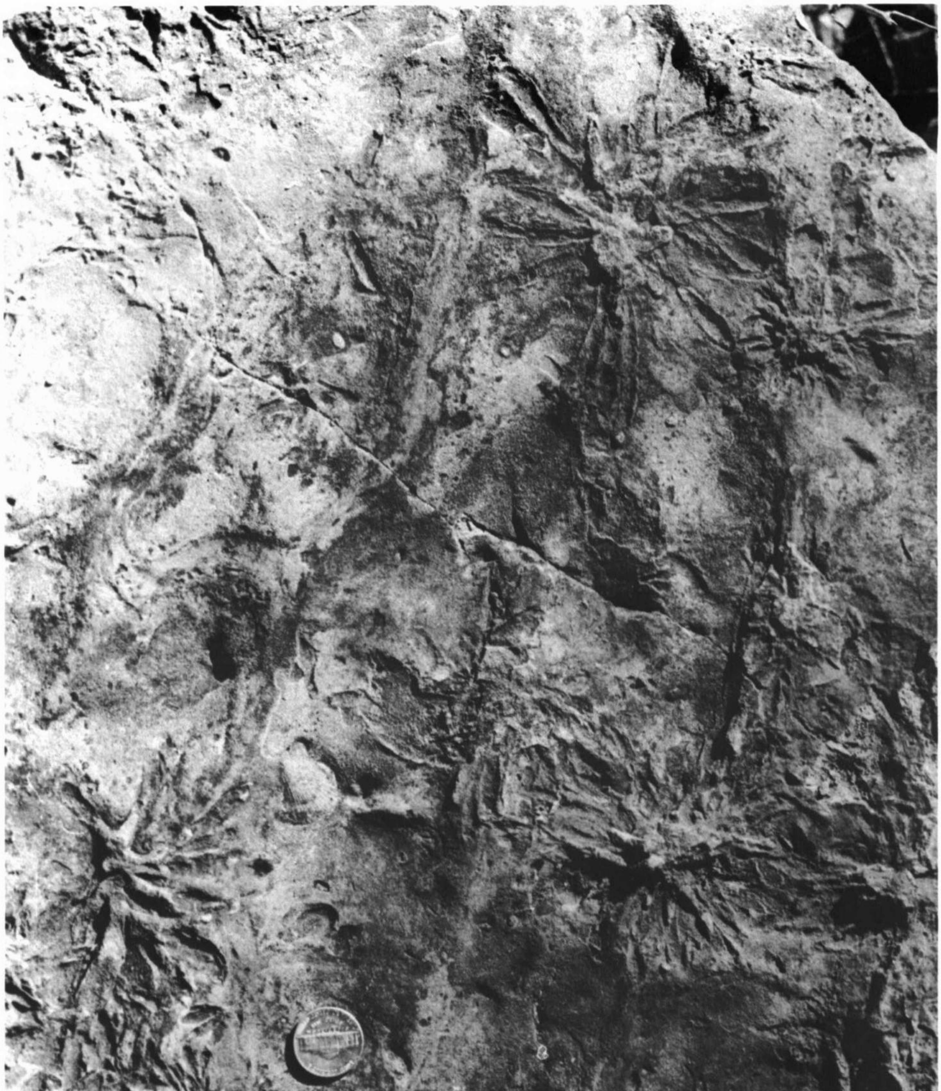
Plate 3, figure 5; Figure 2,*5*.

Trails branching once or several times are superimposed on the rippled surface of a slab from the Rock Lake Shale (Pl. 3, fig. 5; Fig. 2,5). Many trails cross each other but do not unite and are distinctly superimposed on each other. The trails are 4 to 22 mm. long and straight or slightly irregularly curved. Their width varies from less than 1 mm. to 4 mm. The ridges of the trails consist of the same micaceous sandstone as the slab. The preservation is in hyporelief on the underside of the bed.

Some of the thicker trails have many branches as though the trail-making animal advanced into a branch, then returned to the old trail to advance into another branch, thus deepening the older trail through repeated use. This would explain the thinning from the inner to the outer parts of the trail. In places, three sequences of branching can be recognized. The structures are not radial, but

EXPLANATION OF PLATE 1

Asterichnus lawrencensis BANDEL, n. sp., superimposed on rippled surface of sandstone; centers of most structures are oval knobs situated on ripple ridges; shell of *Aviculopecten* in lower left; white circle at base of picture has size of 5-cent coin; KUMIP no. 25146, ×0.4.



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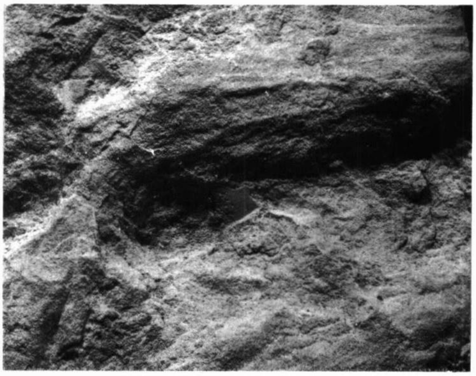

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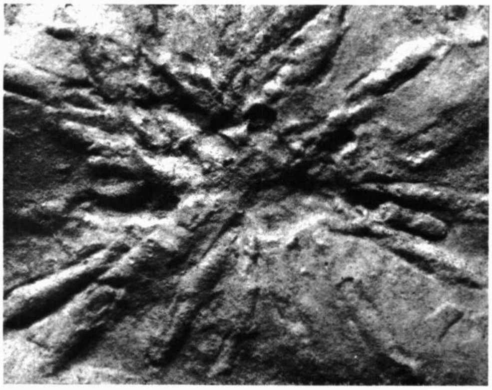

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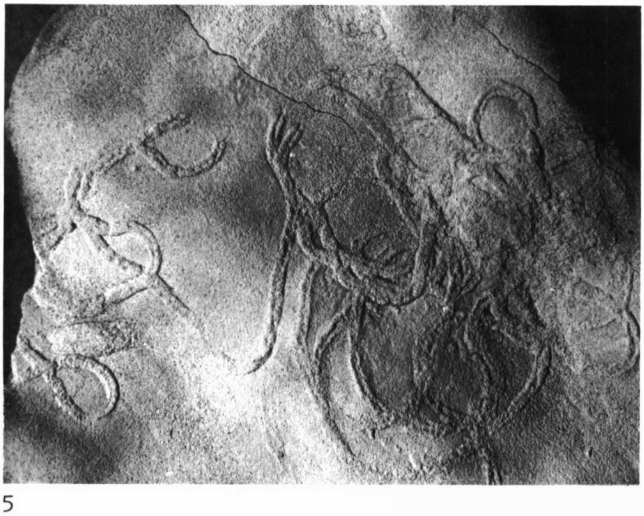

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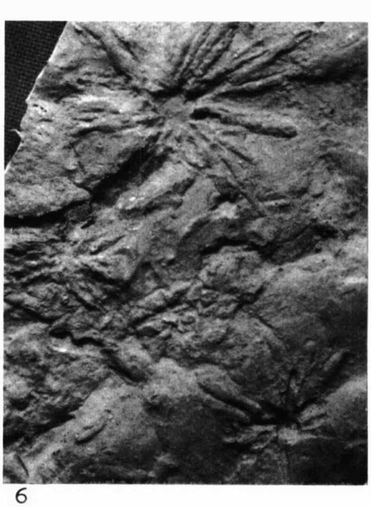

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rather directed more or less in two directions, at about 90 degrees to the axis of the ripples and thus parallel to the current. Only about one in four trails lies in a different direction.

WANNER (1949) pictured and described a very similar trail pattern from the Noric Flysch of the Bula area in East Seran, Indonesia. Size and structure of these trails is the same as the one described above. WANNER named them *Chondrites gonidioides,* because of their similarity to a trail made by the living annelid *Gonidia* studied by NATHORST (1891). NATHORST's Recent structures are radiate but otherwise strikingly similar to the Rock Lake trace fossil. The worm moved foreward from a central burrow in one direction, then retreated and again moved forward in a different direction. He used the old furrow to retreat, but made a new one to cover new feeding ground (NATHORST, 1891).

SOLLAS (1900) and ABEL (1935) pictured and described similar trails. *Chondrites gonidioides* can be regarded as a feeding trail or Fodinichnia (SEILACHER, 1953).

CHONDRITES sp.

Plate 3, figure 6; Figure 4,*1*.

A regularly branched plantlike burrow is preserved in the Vinland Shale on the surface of a septarian concretion (Pl. 3, fig. 6; Fig. 4,*1*). The burrow has ramifications only on one side. The width of the tunnels is the same in all branches.

The structure was probably constructed either as a feeding or as a living burrow. *Chondrites*-like structures are preserved on the bedding planes of many sandstone slabs at the Blue Mound locality, but are generally poorly preserved. Recent polychaete worms construct burrows similar to these (SCHÄFER, 1962).

Genus CROSSOPODIA M'Coy, 1851

CROSSOPODIA DICHOTOMA Bandel, n. sp.

Plate 3, figures 1, 3, 4, 7; Figure 3,*3*.

Diagnosis.—Segmented branching burrows and segmented single burrows and trails; side tracks of both types of structures bifurcate and occur 3 to 4 mm. apart; maximum width of multiple trails 30 mm., of single trails 10 mm.

Description and discussion.—Two kinds of trails are included in this group: single trails used once by an animal, and multiple trails used by a group of animals or by the same animal several times. Trails of the first type are formed either on the bedding plane or as burrows. The epirelief of a crawl trail (Repichnia) was made on the surface of the sediment (Pl. 3, fig. 7). The trail consists of a median furrow with lateral bifurcating branches about 3 to 4 mm. apart. The branches originate from the median furrow at an angle of about 45 degrees, then curve to a position in which they are approximately at right angles. Other single trails were made in the sediment and are preserved as hyporeliefs on the lower surfaces of sandstone beds. The trails may have an articulated appearance (Pl. 3, fig. 4). The side branches are two ridges bifurcating at the point where they branch off from the broad median ridge. The side branches join the median ridge at an angle of less than 90 degrees, and thus the apex formed by the side branches indicates the direction of movement. This type of bedding plane burrow is round (Pl. 3, fig. 4), and the branching structures are imprinted on the walls of the burrow. These trails are 6 to 10 mm. wide and are believed to have been used only once by one animal in the sediment or on its surface.

EXPLANATION OF PLATE 2

FIGURE

1. *Asterophycus* sp., large burrows approximately parallel to bedding plane radiate from a central tube; KUMIP no. 25113, ×0.5.
2. Longitudinally wrinkled surface of an *Asterophycus* burrow; KUMIP no. 25102, ×0.4.
3. *Aulichnites* sp., with undulose outer edges and median line; KUMIP no. 25119, ×1.1.
4. *Asterichnus lawrencensis* BANDEL, n. sp., latex cast showing center knob with radiate cylindrical grooves which continue into feeding burrows in the form of shallow ridges; KUMIP no. 25116, ×0.5.
5. *Aulichnites* sp., feeding trail of a gastropod made while grazing and destroying older trails when crossing them; KUMIP no. 25116, ×0.5.
6. *Asterichnus lawrencensis* BANDEL, n. sp., latex cast, showing different sizes and lack of overlap of tracks; KUMIP no. 25146, ×0.55.

The larger trails (Pl. 3, fig. 1, 3), thought to have been used several times, show the same kind of imprint on the wall of the burrow. The forked side tracks of these trails are separated by the same distance as in the single trails. The multiple trails are up to 30 mm. wide. The best preserved burrow (Pl. 3, fig. 3) branches five times, its maximum width is 30 mm., and minimum width of the branches is 15 mm. In places at least two distinctive trails can be traced on the walls of the same part of the burrow. Probably, several animals used this burrow, or one animal occupied it during a relatively long time. This is also suggested by the greater width of the multiple burrow compared with the single burrows. The side branches of the large burrow turn abruptly upward and continue into the sandstone and possibly they went on to the surface. Lateral branches of a multiple trail which is 20 mm. wide, are 6 mm. wide and are similar to the single trails.

The wide multiple trails can be considered as dwelling burrows (Domichnia) and the narrow single burrows as feeding trails (Fodinichnia) or crawling trails (Repichnia). The originator of these trails probably was an animal with chelicerate appendages. The study of Recent annelid and crustacean burrows might possibly clear up the origin of burrows of this type.

Some of the side branches of the larger burrows show similarity to the trace fossil *Crossopodia*, the described species of which are only superficially similar to the Vinland Shale trace fossils.

Occurrence.—Vinland Shale Member, Blue Mound, and Rock Lake Shale Member, Eudora, Douglas Co., Kansas.

Holotype.—Museum of Invertebrate Paleontology, University of Kansas, no. 25103.

Genus CYLINDRICHNUS Bendel, n. gen.

Type species.—*Cylindrichnus reptilis* BANDEL, n. sp.

Diagnosis.—Trail made of ball-like structures which are either unconnected or connected by ridge of same width as diameter of balls.

CYLINDRICHNUS REPTILIS Bandel, n. sp.

Plate 3, figure 2; Plate 4, figures 1,5; Figure 2,2.

Diagnosis.—Ball-like structures of 15 to 30 mm. diameter, commonly aligned like string of pearls, rarely connected by ridge with crescentic transverse grooves; thought to be trail of large wormlike, sediment-feeding animal which packed its fecal pellets in mucus.

Description and discussion.—Sandstones in the upper part of the Rock Lake Shale contain abundant trace fossils in the form of round, vertically compressed balls of the same lithology as the rock body (Pl. 3, fig. 2; Pl. 4, fig. 5). The balls have recognizable internal structure. Some of them impinge on others, thereby altering the shape of the adjacent balls. It seems probable that the balls were originally spherical and that because of compaction of the sediment, they became vertically compressed. Their length ranges from 15 to 30 mm., their height from 5 to 15 mm.

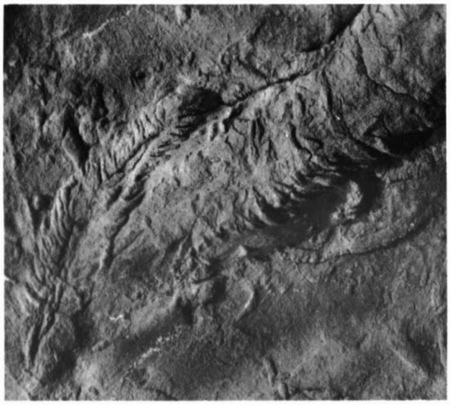
Some balls are arranged in a line like pearls on a string (Pl. 4, fig. 5). They are rarely connected with each other by ridges which generally show crescentic transverse grooves (Pl. 4, fig. 1).

TEICHERT (1941, p. 384, fig. 4) pictured a trail from the Permian Wandagee Series of Minilya River in Western Australia, which is very similar to the Kansas trails; the diameter of the Australian balls is 20 to 25 mm.[1] TEICHERT interpreted these structures as trails of large mud-eating worms.

EXPLANATION OF PLATE 3

FIGURE

1. Two burrows of *Crossopodia dichotoma* BANDEL, n. sp., of feather-like appearance; bilobate trails at lower right are *Gyrochorte*; KUMIP no. 25105, ×0.5.
2. *Cylindrichnus reptilis* BANDEL, n. sp., like a string of pearls, interpreted as fecal trail of a large wormlike animal; photograph taken in the field, ×0.16.
3. Segmented branching burrow of *Crossopodia dichotoma* BANDEL, n. sp., used more than once; side branches continuing into sandstone; *Pelecypodichnus* mark in lower right; KUMIP no. 25103, ×2.4.
4. Single burrow of *Crossopodia dichotoma* BANDEL, n. sp., having segmented appearance and round diameter, and other *Crossopodia* burrows; KUMIP no. 25145, ×1.2.
5. *Chondrites gonidioides* WANNER, small branching tracks on surface of sandstone bed; structures oriented perpendicular to the axes of the ripples; KUMIP no. 25108, ×0.8.
6. *Chondrites* sp., with *Crossopodia* burrow at left; KUMIP no. 25114, ×1.2.
7. Single surface trail of *Crossopodia dichotoma* BANDEL, n. sp.; KUMIP no. 25104, ×0.8.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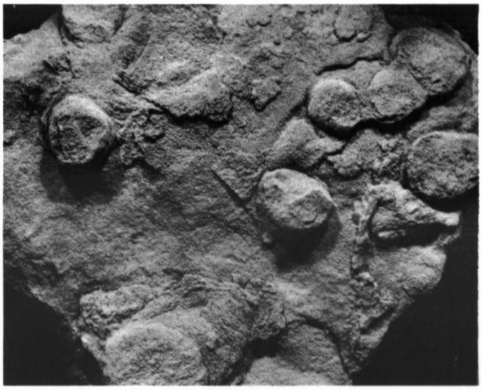
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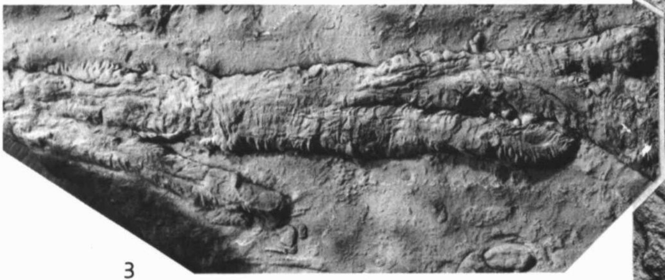
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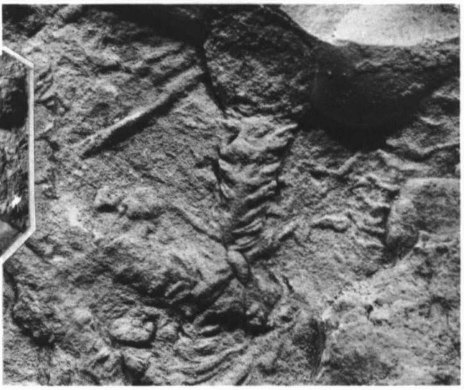
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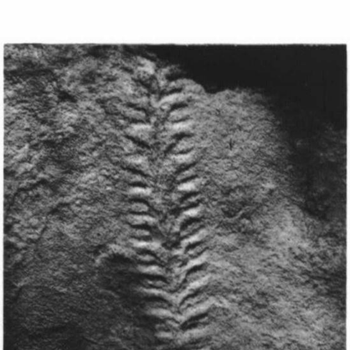
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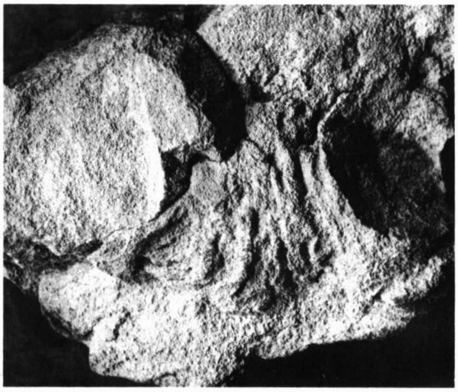

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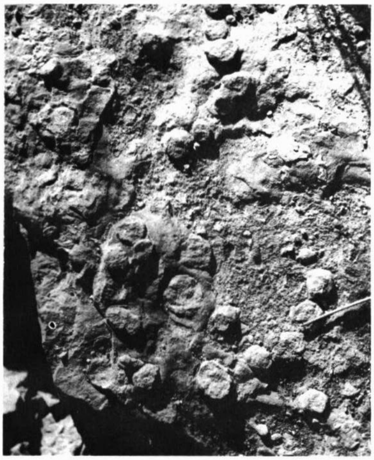

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FENTON and FENTON (1934) described *Arthraria*-like structures made on the surface of sediment by the snail *Ilyanassa obsoleta* (SAY) and compared them to the trace fossil genus *Arthraria* BILLINGS. Both types of structures differ from the Rock Lake Shale trails in having narrower trail or burrow connecting the cylindrical structures, whereas ridges connecting balls in *Cylindrichnus* are of the same diameter as the balls.

Origin.—The ball-like structures are believed to be fecal pellets. SCHÄFER (1962, p. 470-474) found that pellets must be either compacted or packed in mucus in order to be preserved. The producer of *Cylindrichnus* probably was a large wormlike animal. It is probable that the trails were not formed on the surface of the sediment but below the surface. The lithologies of the sandstone above and below the trail layers are identical and only a thin film of silt separates the beds. This film might have been especially rich in organic content. *Cylindrichnus* could have been formed by sipunculids or by priapulids. The large diameter of the balls seems to rule out polychaetes, at least if Recent representatives are considered.

Occurrence.—Rock Lake Shale Member, Eudora, Douglas County, Kansas.

Holotype.—Museum of Invertebrate Paleontology, University of Kansas, no. 25109.

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[1] It should be noted that in TEICHERT's paper the explanation of figures 3 and 4 have been inadvertently interchanged. The occurrence is either in the Wandagee Formation or in the Nalbia Sandstone as now understood (TEICHERT, personal communication).

Genus GORDIA Emmons, 1844

GORDIA sp.

Plate 4, figures 6, 7; Figures 2,*1*; 4,*4*.

Long slender wormlike trails found in both localities on bedding planes or together with burrows believed to have been formed between bedding planes (Pl. 4, fig. 7). Some curving trails from the Rock Lake Shale terminate in small circular pits which can be interpreted as casts at the beginning of burrows leading into the sediment. The trails from the Vinland Shale are not terminated by pits. Both trail types are preserved as hyporeliefs on the underside of sandstone beds.

Worms, wormlike animals, amphipods (HÄNTZSCHEL, 1939), or small snails could have formed these trails. ABEL (1935) pictured some trails of worms made on wet sand of North Sea intertidal flats which are similar to these fossils. HÄNTZSCHEL (1940) showed that movement of *Nereis* on the sediment surface causes starlike tracks and also simple curving trails. The connection of the fossil trails with pits in which they end suggests that part of the worm remained in its burrow and another part crawled on the sediment, and could retract into its burrow by using the old trails again. DESIO (1940, pl. 6, fig. 4) pictured a trail from Paleozoic sandstones of Lybia which is very much like the Rock Lake Shale trails and interpreted it as being of annelid origin. The *Gordia* from the Vinland Shale was probably formed in the sediment, not on the sediment surface, as the Rock Lake Shale trail. The animal

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EXPLANATION OF PLATE 4

FIGURE

1. Two ball-like fecal pellets of *Cylindrichnus reptilis* BANDEL, n. sp., connected by ridge with concentric transverse grooves; KUMIP no. 25110, ×1.35.

2. Almond-shaped *Pelecypodichnus ornatus* BANDEL, n. sp., with concentric rib impressions and spicate trail leading away from rest place; structure made by a bivalve; KUMIP no. 25101, ×1.35.

3. *Pelecypodichnus ornatus* BANDEL, n. sp., with concentric rib impressions, probably made by the animal leaving rest place vertically; KUMIP no. 25101, ×1.35.

4. *Pelecypodichnus ornatus* BANDEL, n. sp., trail and irregular rest place at its end; KUMIP no. 25101, ×1.35.

FIGURE

5. *Cylindrichnus reptilis* BANDEL, n. sp., showing overlapping ball-like fecal pellets and connecting ridges; KUMIP no. 25109, ×0.45.

6. Burrows of *Gyrochorte* sp., along bedding plane; bilobate structures cross each other with one passing above or below the other; at right narrow trail of *Gordia* without terminal pit; KUMIP no. 25106, ×0.9.

7. *Gordia* sp., made on the sediment probably by a worm, preserved on underside of a sandstone bed, trails end in a little groove; round structure at right is *Planolites* sp.; KUMIP no. 25115, ×1.8.

must have followed bedding planes in search for food. Both trails can be interpreted as feeding trails (Fodinichnia).

Genus GYROCHORTE Heer, 1865

GYROCHORTE sp.

Plate 3, figure 1; Plate 4, figure 6; Figure 4,*5*.

The undersides of some sandstone beds in the Vinland Shale are completely covered with simple bilobate trails (Pl. 4, fig. 6), 1 to 7 mm. wide, which superficially resemble the gastropod trail *Aulichnites*. They form ridges in epirelief, marked by a median furrow. Some burrows show irregularities such as undulations of the outer edge of the ridges and the median line or irregular lobes with smooth surfaces aligned along the ridges. This might indicate that the burrow was filled in by the burrowing animal.

The trails may cross each other, one passing above or below the other without destroying the older structure. Commonly, they penetrate each other and the younger trail follows the older one for a short distance, penetrating it to the median line but not following the old course exactly. These trails are not like gastropod trails made on the surface, because *Aulichnites* does not show such features. When gastropod trails cross, the newer one destroys the older, or if more than one animal follows the same trail, this is not evident, unless the trails branch. Burrowing gastropods, worms, or small crustaceans could have formed trails of the appearance of *Gyrochorte*.

Such trails might occur in any formation (Seilacher, 1964). *Gyrochorte carbonaria* is extremely abundant in the Upper Carboniferous cyclothem sequences of the Ruhr basin in Germany.

Genus PELECYPODICHNUS Seilacher, 1953

PELECYPODICHNUS ORNATUS Bandel, n. sp.

Plate 4, figures 2, 3, 4; Plate 5, figure 1; Figure 4,*3*.

Diagnosis.—Almond-shaped trace fossils with ornamentation suggesting concentric ribs or growth lines, connected with spicate structures consisting of median ridge and ridges branching opposite each other from it.

Description and discussion.—Some of the slabs from the Blue Mound locality have small podlike or almond-shaped trace fossils (Pl. 4, fig. 2, 3; Pl. 5, fig. 1). Two of these (Pl. 4, fig. 2, 3) show impressions of concentric ribs or growth lines, suggestive of a bivalve. The tracks are therefore interpreted as rest marks (Cubichnia) of bivalves.

One slab of 480 cm.^{2} has eight bivalve rest marks of the type which Seilacher (1953) called *Pelecypodichnus*. Their axes do not appear to be oriented. Almost all of the *Pelecypodichnus* marks are found in connection with locomotion trails of the animal leading to or from the resting places. In two cases these trails are preserved for a distance of about 4 times the length of the *Pelecypodichnus* rest mark (Pl. 4, fig. 2). Most are shorter and disappear into the sandstone as if moving upward, possibly to escape burial by sedimentation. In one case three rest marks are connected with each other by a crawl trail (Pl. 5, fig. 1). The trail of another bivalve cuts across some bilobate aggregates interpreted as bedding plane burrows *(Crossopodia dichotoma)*, suggesting a completely buried mode of life of this bivalve.

EXPLANATION FOR PLATE 5

FIGURE

1. *Pelecypodichnus ornatus* Bandel, n. sp., trails connecting different resting places and crossing each other; large round knob in upper right is a *Crossopodia* burrow; KUMIP no. 25103, ×1.2.

2. Tubercles on underside of a sandstone bed forming a trail that is not bunched together in a tube or aggregate; burrow at left is *Crossopodia* sp.; KUMIP no. 25103, ×0.8.

3. Fecal trails, with *Crossopodia* burrows and bivalve rest tracks; trail at right is made of smooth surfaced tubercles and has larger diameter than the trail on left which also is more irregular in shape; KUMIP no. 25154, ×0.5.

4. Irregularly outlined burrows of *Planolites montanus* Richter, made by wormlike animals; KUMIP no. 26112, ×0.5.

5. *"Spreiten"* structure of *Zoophycos* sp. made of one thin tube having many side branches; KUMIP no. 25101, ×0.8.

6. Smooth slender burrows of *Planolites* sp., having round cross-sections and curving irregularly through the sediment; KUMIP no. 25120, ×0.8.

1

2

3

4

5

6

The trails are spicate with forked ridges branching from the median ridge on both sides and opposite each other (Pl. 4, fig. 2, 4; Pl. 5, fig. 1). The convex side of the branches indicates the direction of movement. *Pelecypodichnus*, which has the concentric ornamentation of its maker, is a rest mark, not an external mold, because the crawl trail connected to this structure leads away from it (Pl. 4, fig. 2). Other *Pelecypodichnus* rest marks are preserved at the end of crawl trails (Pl. 4, fig. 4).

The excellent preservation of the external structures of the bivalve shell can be explained by the presence of a shale bed below the sandstone. The bivalve had penetrated into the shale with its anterior end, while the posterior end, through which currents of water enter and leave the animal, was situated in the sand.

The bivalve moved with the ventral side forward. Probably, it advanced by extending its foot into the sand, then the tip of the foot swelled and acted as an anchor, the muscles of the foot contracted, drawing the body of the clam forward, as Recent bivalves do.

These Pennsylvanian tracks are judged to differ specifically from Mesozoic *Pelecypodichnus amygdaloides* (SEILACHER).

Occurrence.—Vinland Shale Member, Blue Mound, Douglas County, Kansas.

Holotype.—Museum of Invertebrate Paleontology, University of Kansas, no. 25101.

Genus PLANOLITES Nicholson, 1873

PLANOLITES MONTANUS Richter, 1937

Plate 5, figure 4; Figure 2,6.

Planolites montanus RICHTER, 1937, p. 151, fig. 1-5.

Some burrows in the Rock Lake Shale Member, about 1 cm. wide, penetrate the rock irregularly and in varying directions (Pl. 5, fig. 4). The sand and silt filling of the burrows was probably brought in by the presumably wormlike animal after passing through its alimentary canal. No branching of burrows could be noticed.

Planolites montanus is useful in distinguishing members of the paralic Upper Carboniferous cyclothems of the Ruhr Basin in Germany. The Rock Lake Shale burrows are very similar.

PLANOLITES sp.

Plate 4, figure 7; Plate 5, figure 6; Figure 2,4.

Some unornamented tubes, 3 to 4 mm. wide, with round cross section occur in the sandstones of the Rock Lake Shale (Pl. 5, fig. 6). They were probably made by sediment-feeding wormlike animals and filled in by them. The burrows are thinner and more regular in shape than the burrows described as *Planolites montanus*. Some are parallel to each other and do not cross.

Genus ZOOPHYCOS Massalongo, 1855

ZOOPHYCOS sp.

Plate 5, figure 5; Figure 4,6.

This *"Spreiten"* structure occurs in the Vinland Shale with rest marks and crawl trails of bivalves. It consists of one thin tube with numerous side branches that are parallel to each other, each forming a shallow basin (Pl. 5, fig. 5). It is probably only a flat nonspiral variety of *Zoophycos*, differing from the ones described by ABEL (1935, fig. 365-369). These structures are known from the Atoka Series of the Ozarks and of Arkansas (HENBEST, 1960). *Zoophycos* is thought to be restricted to deep-water and flysch environments, but has lately been described from such shallow-water rocks as the Triassic Buntsandstein of Germany (SEILACHER, 1963) and the marine phases of Illinois cyclothems of the Pennsylvanian (HENBEST, 1960).

This structure is regarded as a feeding burrow (Fodinichnia). Feeding took place along bedding planes in the sediment.

FECAL TRAILS

Plate 5, figure 3; Figure 4,2.

Associated in the Vinland shale with *Pelecypodichnus ornatus* and *Crossopodia dichotoma* is a trail that consists of smooth wartlike tubercles (Pl. 5, fig. 3). This trail is preserved in hyporelief on the underside of sandstone beds. Absence of apparent order of position of the tubercles distinguishes it from the Jurassic *Neonereites biserialis* and *N. uniserialis* (SEILACHER, 1960). The originator of the trail was either a burrowing animal that fed on sediment and left a fecal trail of aggre-

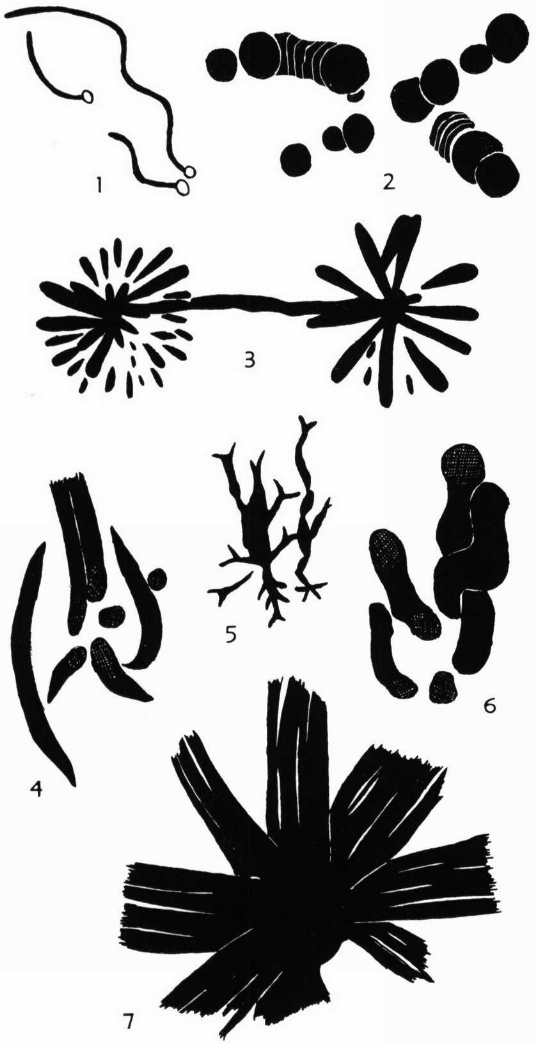

FIG. 2. Trace fossils restricted to Rock Lake Shale.——*1. Gordia* sp., ×1.——*2. Cylindrichnus reptilis* BANDEL, n. sp., ×1.——*3. Asterichnus lawrencensis,* BANDEL, n. sp., ×0.5.——*4. Planolites* sp., ×1.——*5. Chondrites gonidioides* WANNER, ×1.——*6. Planolites montanus* RICHTER, ×0.7.——*7. Asterophycus* sp., ×1.

gated pellets or that filled its burrow with fecal pellets.

A more irregular mass of fecal pellets occurs in a structure very similar to that described above (Pl. 5, fig. 3). These fecal pellets are much smaller and not arranged in a straight tubelike trail, but rather to form two connected irregularly round aggregates. This structure is adjacent to a *Crossopodia* burrow.

Another structure, made of tubercles on the underside of sandstone beds shows tubercles arranged in rows of three without being bunched together in a tube or in aggregates (Pl. 5, fig. 2). It is not clear whether this structure was made on the surface of the sediment or on the bedding plane as other tracks associated with it.

The uniting factor of the three very different structures from the Vinland Shale is that their single components resemble fecal pellets.

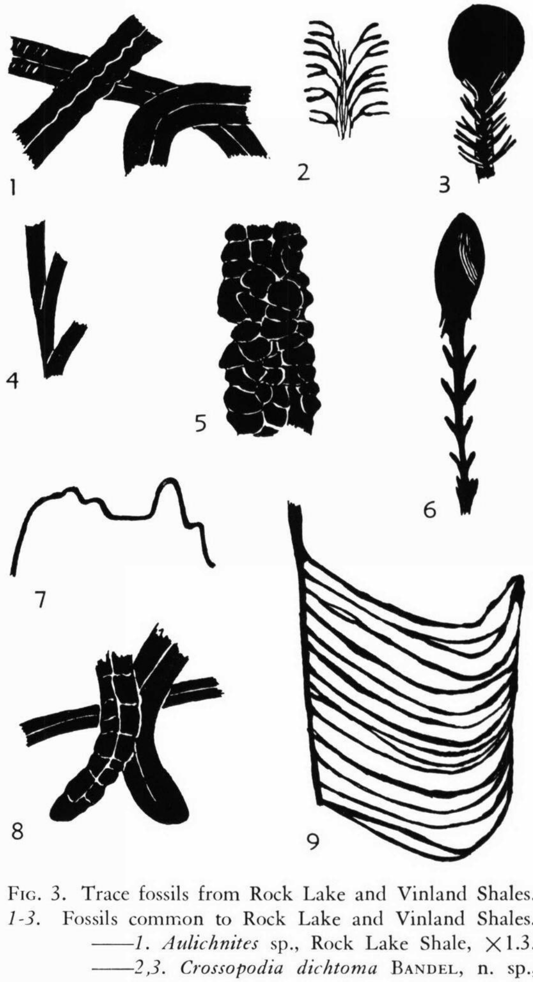

FIG. 3. Trace fossils from Rock Lake and Vinland Shales.

1-3. Fossils common to Rock Lake and Vinland Shales. ——*1. Aulichnites* sp., Rock Lake Shale, ×1.3. ——*2,3. Crossopodia dichtoma* BANDEL, n. sp., ×1, ×3.

4-9. Fossils restricted to Vinland Shale.——*4. Chondrites* sp., ×1.5.——*5.* Fecal trails, ×1.——*6. Pelecypodichnus ornatus* BANDEL, n. sp., ×0.7.——*7. Gordia* sp., ×2.——*8. Gyrochorte* sp., ×1.——*9. Zoophycos* sp., ×1.

COMPARISON OF ICHNOFACIES

The Rock Lake Shale trace fossils include six different types made in the sediment and three types made on the sediment. Their proportion in the Vinland Shale is five to three.

ROCK LAKE SHALE TRACE FOSSILS

1. *Asterichnus lawrencensis* BANDEL, n. sp. (Fig. 2,*3*), subsurface track of Fodinichnia type, made by a semisessile deposit feeder.

2. *Asterophycus* sp. (Fig. 2,*7*), starlike subsurface trail made by large burrowing organisms; possibly dwelling burrow (Domichnia) or the central part of a Fodinichnia structure made by mud-eaters.

3. *Chondrites gonidioides* WANNER (Fig. 2,*5*), feeding trail probably made from a central burrow; should probably be classed as Fodinichnia.

4. *Cylindrichnus reptilis* BANDEL, n. sp. (Fig. 2,*2*), subsurface trail made by a mud-eating wormlike animal, belonging to Pascichnia. The trail was made by a vagile mud-eater exploiting a horizontal bed of probably higher food particle content than beds below and above.

5. *Gordia* sp. (Fig. 2,*1*), track made on the sediment surface by an animal that lived in a burrow and extended part of its body out of the sediment, probably in order to feed; belongs to Fodinichnia.

6. *Planolites montanus* RICHTER (Fig. 2,*6*), trails seemingly filled with sediment that had passed the alimentary system of a wormlike organism; Pascichnia type.

7. *Planolites* sp. (Fig. 2,*4*), trail made in the same fashion as *Planolites montanus* and thus, of Pascichnia type.

TRACE FOSSILS COMMON TO ROCK LAKE SHALE AND VINLAND SHALE

1. *Aulichnites* sp. (Fig. 3,*1*), gastropod trails; the strongly curved trails are grazing trails (Pascichnia), the straight trails crawling trails (Repichnia).

2. *Crossopodia dichotoma* BANDEL, n. sp. (Figs. 3,*2*,*3*), trails made by a segmented animal; single and multiple trails present; only one multiple trail known from the Rock Lake Shale; one crawling trail (Repichnia) found at Blue Mound; the bulk of trace fossils belonging to this group are burrows of Fodinichnia and, perhaps, Domichnia type.

VINLAND SHALE TRACE FOSSILS

1. *Chondrites* sp. (Fig. 4,*1*), burrow made by a semisessile, deposit feeding wormlike animal to be classed as Fodinichnia type.

2. *Gordia* sp. (Fig. 4,*4*), not associated with pits; probably formed in the sediment as a Pascichnia form.

3. *Gyrochorte* sp. (Fig. 4,*5*), feeding burrows made by deposit-feeding vagile animals that filled their burrow with sediment that had passed the alimentary system (Pascichnia).

4. *Pelecypodichnus ornatus* BANDEL, n. sp. (Fig. 4,*3*), associated resting tracks (Cubichnia) and crawling trails (Repichnia) of a bivalve.

5. *Zoophycos* sp. (Fig. 4,*6*), bedding plane *"Spreiten"* trail made by deposit-feeding animal. The wormlike animal may have lived for a long time in part of this structure or it may have been vagile. It may therefore be classed in either the Fodinichnia or the Pascichnia group.

6. Fecal trails (Fig. 4,*2*), either surface structures or filled burrows that do not fit into any of the five recognized trace fossil categories.

CONCLUSIONS

The trace fossils from the Rock Lake Shale can be subdivided into four Fodinichnia trails, three Pascichnia trails, and one Repichnia trail. The Vinland Shale contains two Fodinichnia, one Pascichnia, two Repichnia, two Domichnia, and one "fecal type" trace fossil.

The animals that produced trace fossils of both localities must have been quite different, because only *Crossopodia dichotoma* and the insignificant gastropod trail *Aulichnites* are found in both localities. Both sandstones are marine. Although shell fossils in both units are similar, the great difference in trace fossil assemblages indicates differences in environments. The trace-fossil fauna of both localities belongs to the *Cruziana*-facies of SEILACHER (1964) which is characteristic of littoral and shallow-water environments. Other evidence for deposition in shallow coastal waters are the small coal lenses in the Vinland Shale not far from Blue Mound (O'CONNOR, 1960) and the abundant wood fragments in the sandstones of both members.

It seems possible that with the help of trace fossils the paleoenvironment of the Pennsylvanian sandstones can be interpreted in much more detail than just as marine, mixed, or fresh-water origin. When sufficient knowledge of these structures has been obtained, it should be possible to identify some indicator trace fossils for different environments.

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